




Effectively Managing Turnarounds and Shutdowns In Low Earth Orbit

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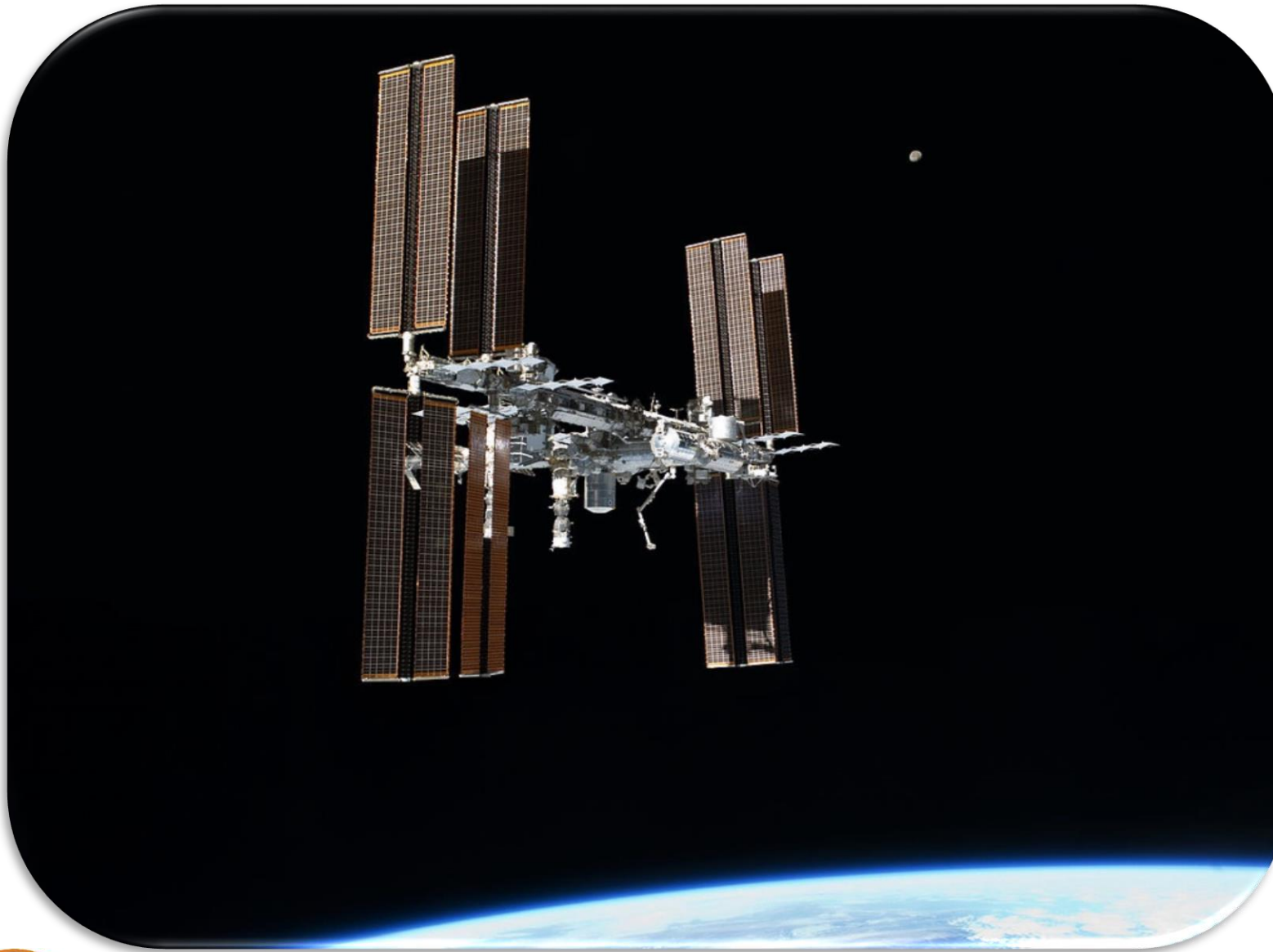
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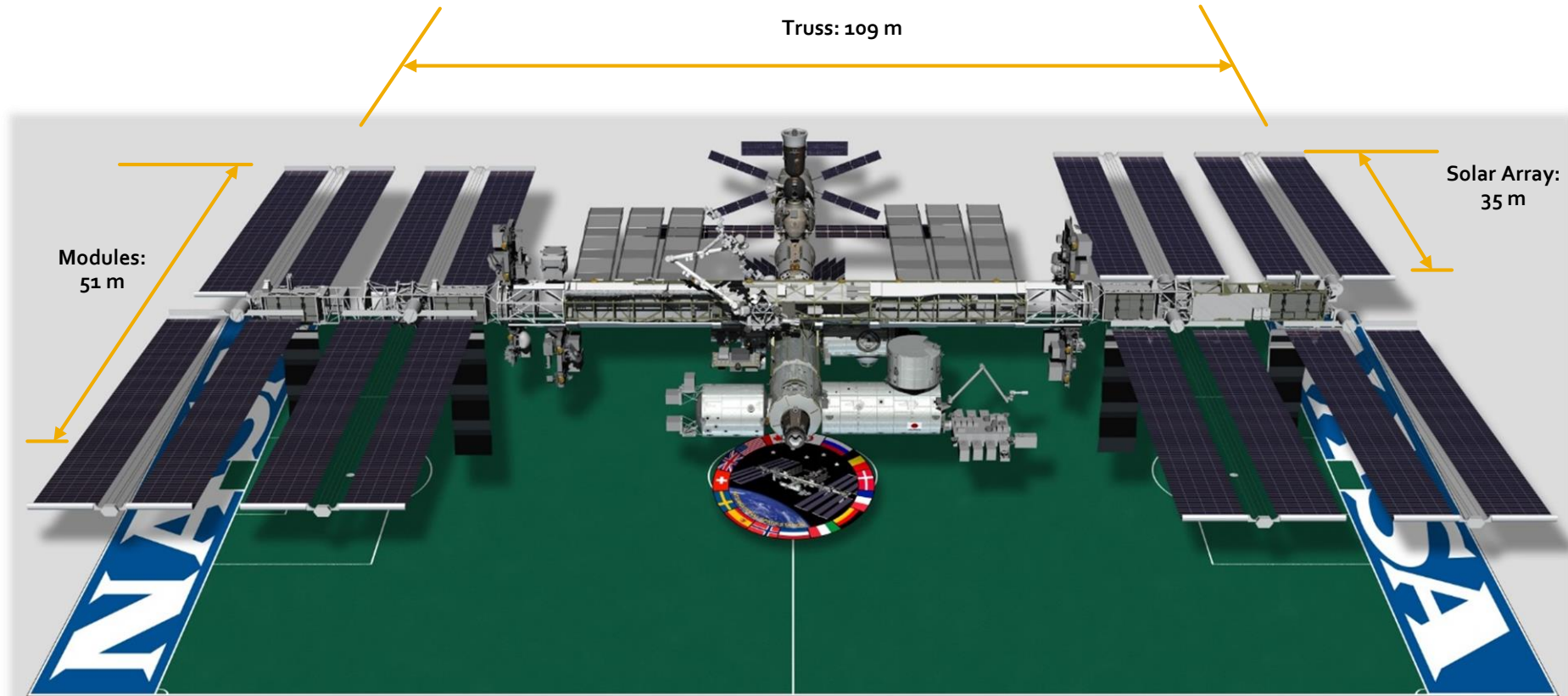
International Space Station



- Microgravity research laboratory assembled in orbit between 1998-2011
- Occupied continuously since 2000
- Components built by companies across 16 nations
- 170+ launches from Florida, Virginia, Russia, Japan, and French Guiana
- Research crew of 6 astronauts and cosmonauts serve 6 month stay



Earth's Only Microgravity Research Laboratory



LARGE, CAPABLE LABORATORY:

Mass: 420,000 kg
Habitable Volume: 388 m³
Solar Power Generation Capability: 84 kW
Numerous external and internal research platforms

REMOTE OUTPOST:

Altitude: 415 km (250 mi)
Orbital Speed: 28,000 kph (7.8 km/sec)
17,500 mph (5 mi/sec)
Orbital Period: 90 minutes
(16 sunrises/sunsets per day)

ISS Assembly



- **163 launches to ISS between Nov 1998 and Nov 2015**
 - 37 U.S. space shuttle assembly missions to ferry components, logistics, consumables, research, and crew between Earth and ISS
- **Space Shuttle was primary vehicle used to assemble ISS**
 - Tremendous mass-to-orbit and orbit-to-Earth capability
 - Carried up to 7 crewmembers
 - Capability for up to ~10 docked days
 - Had its own airlock and robotic arm
 - Crew training occurred up until very close to launch
 - » Late changes could be absorbed as the crews launched from the US



ISS018E008788



Supportability & Logistics



- **Original plan**
 - US Orbital Segment designed to be launched and serviced by the space shuttle
 - Maintenance concept centers on the “Orbital Replacement Unit” (ORU)
 - Minimize turnaround downtime by doing depot-level maintenance on Earth and reflly the hardware
- **Plans changed – shuttle retirement**
 - Launch as many repair parts, especially parts only shuttle could launch, before the program ended
 - Develop new means and methods for diagnostics and troubleshooting as well as in-situ repair
 - Next generation spare parts now being designed to use same footprint but have separate, stand-alone components that are able to be launched on today’s rockets
- **Lesson: Anticipate paradigm shifts if you can**
 - ISS was designed in the 1980s and 1990s when the expectation was that space shuttle would fly forever
 - Adapting now is much harder and likely much more expensive



Logistics Skip Cycles

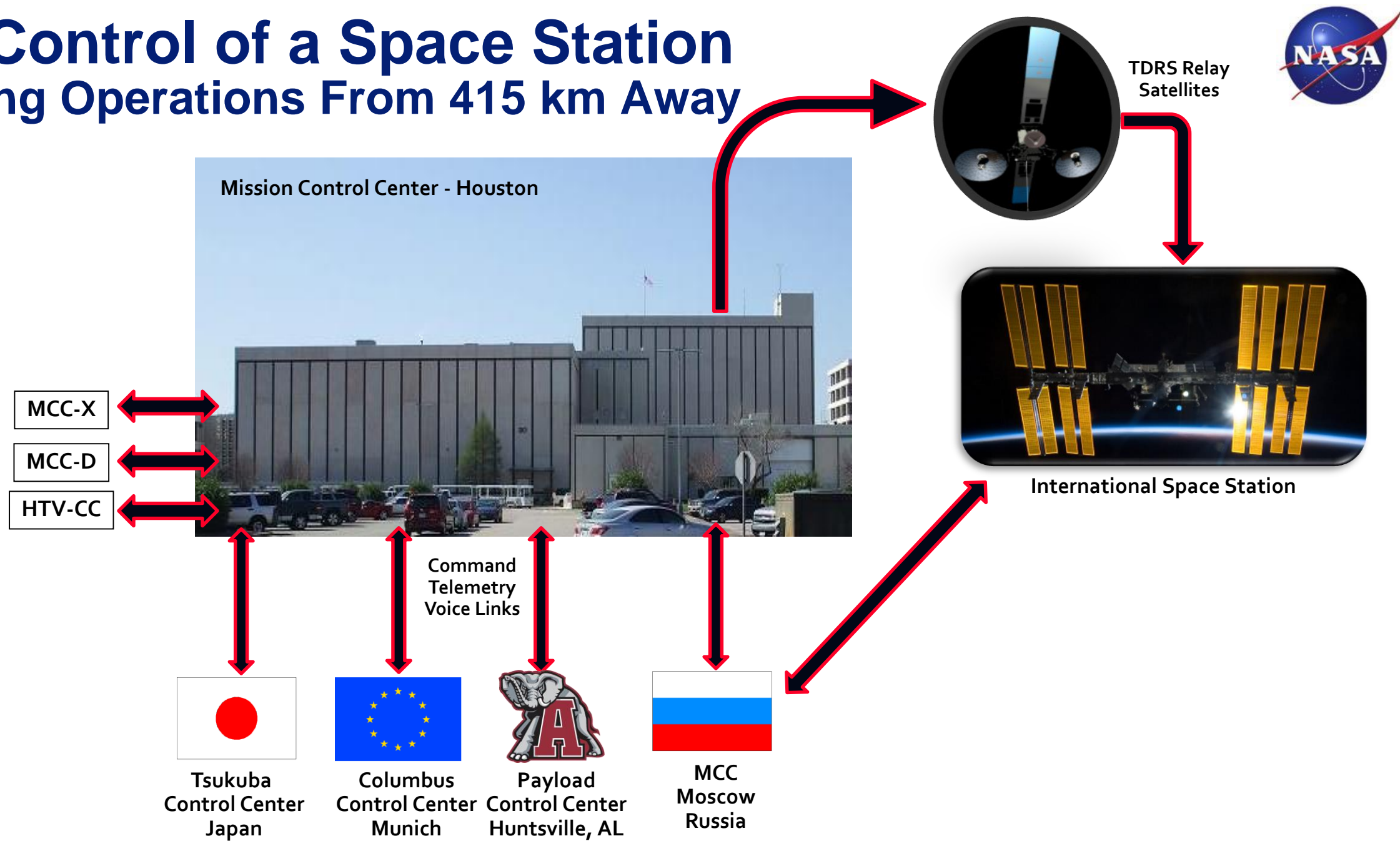
Planning for Unexpected 'Shutdowns'

- ISS resupply requires Earth-launched cargo missions
- Spaceflight is complex and HARD
 - Launch schedules change frequently
 - Mission/cargo needs change
 - Weather happens
 - Rapid Unplanned Disassembly (RUD) happens
 - » Orbital Sciences “Orb-3” loss after liftoff 28 Oct 2014
 - 2,200 kg lost
 - » Russian Progress 59P loss at 3rd stage separation 28 Apr 2015
 - 2,400 kg lost
 - » SpaceX CRS-7 loss during 1st stage 28 June 2015
 - 1,900 kg + International Docking Adapter lost
 - » SpaceX AMOS-6 loss ~4 minutes prior to engine test
 - USD \$195M satellite, rocket, lost; significant launch pad damage
- Plan a skip cycle so you can tolerate schedule changes or logistics losses
 - ISS currently uses ~4-6 month skip cycles for critical consumables



Remote Control of a Space Station

Orchestrating Operations From 415 km Away



Mission Control Center – Houston



**Flight Operations Directorate
Flight Director Office**



MBSU Failure – Fall 2011

When a Choreographed Turnaround Turns into An Unplanned Shutdown

- **Main Bus Switching Unit (MBSU)**
- **Key piece of hardware that routes primary power (~160 VDC) from the 8 solar array-fed power channels to downstream load distribution equipment**
 - 4 MBSUs on ISS, each routing 2 power channels
 - Each can be 'cross tied' to 2 other MBSUs in times of failure so other channels can power a MBSU's loads
 - Computer commands direct the opening/closing of switches in each MBSU to perform power routing
 - » Switch states are generally not changed (can go unchanged for months at a time)



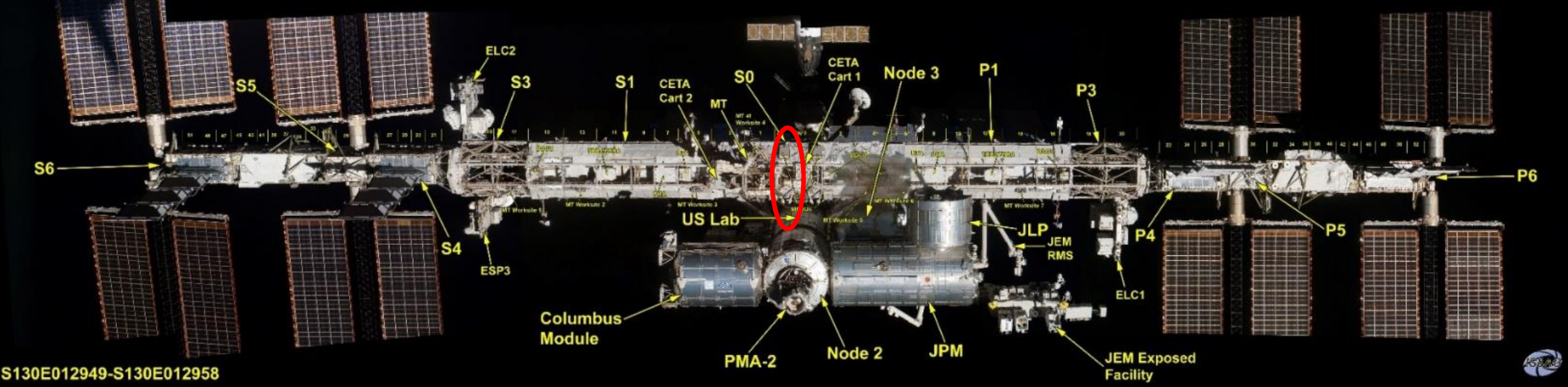
MBSU Failure – Fall 2011

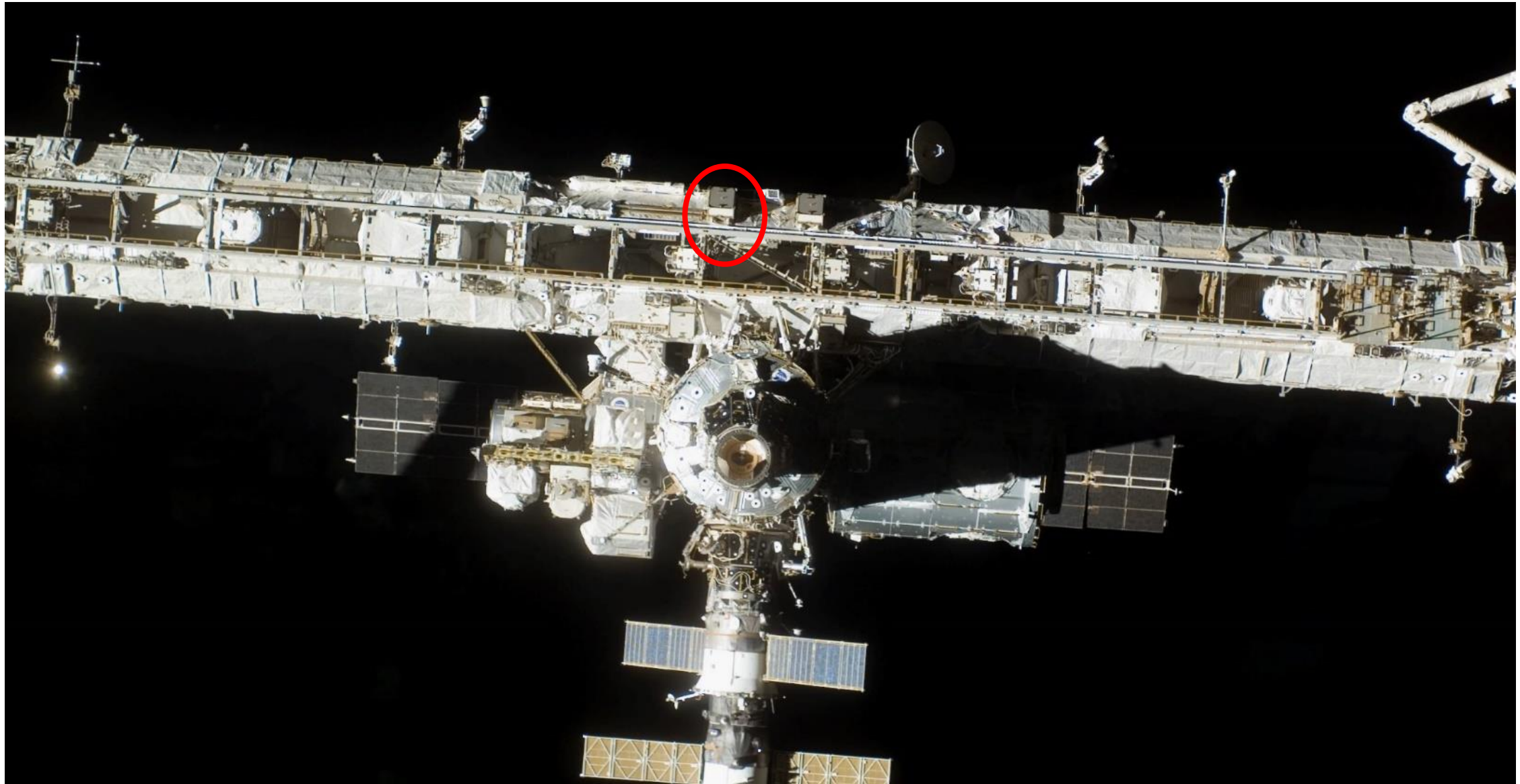


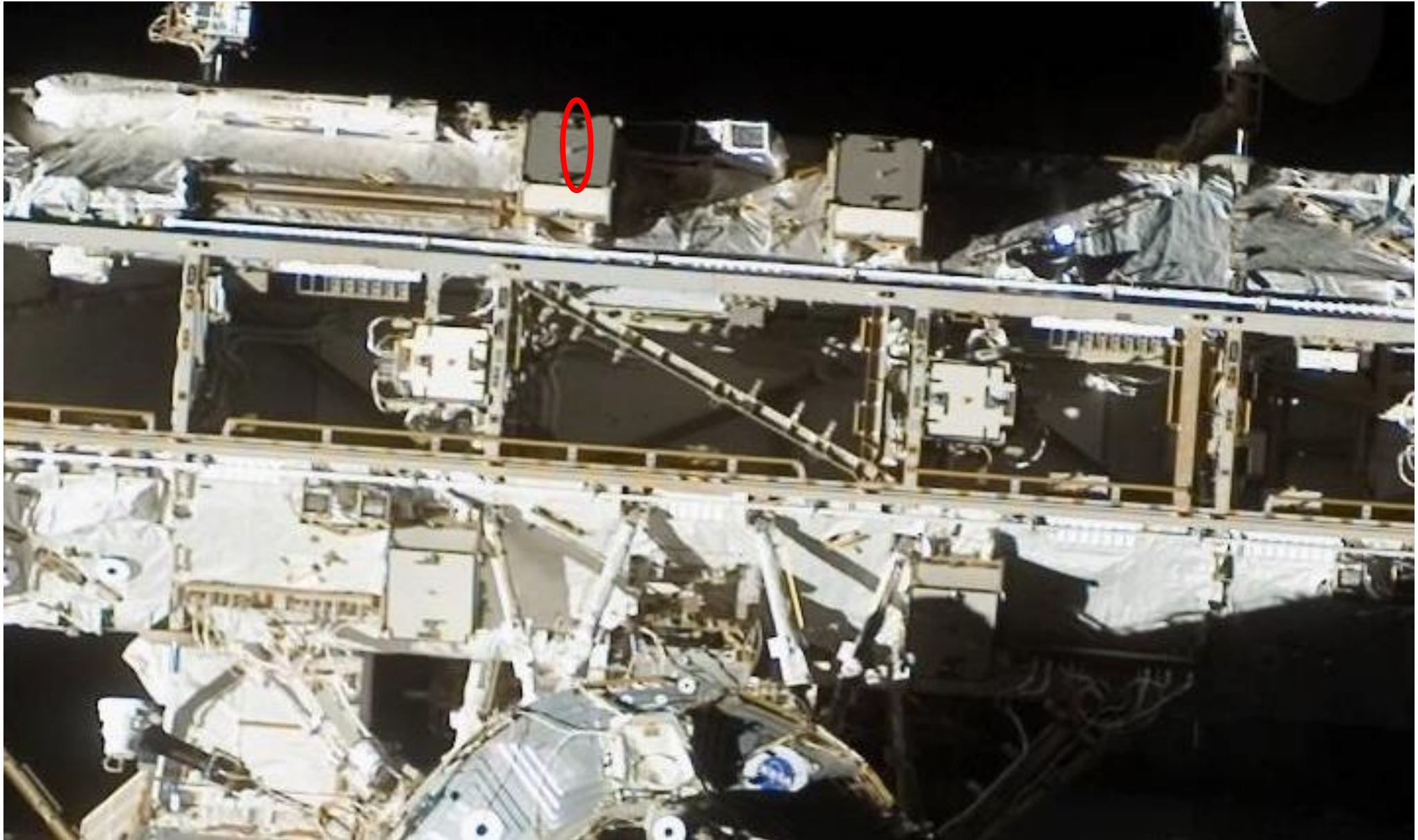
- **MBSU 1 had a circuit card failure in Fall 2011 where it stopped communicating with its controlling computer**
 - Switches remained open/closed, power was still being passed, but switch position could not be changed
- **Decided the current condition was acceptable in the short term but the MBSU needed to be replaced “soon”**
 - Replacement spacewalk targeted for Fall 2012



Forward Side of ISS
AF-20A







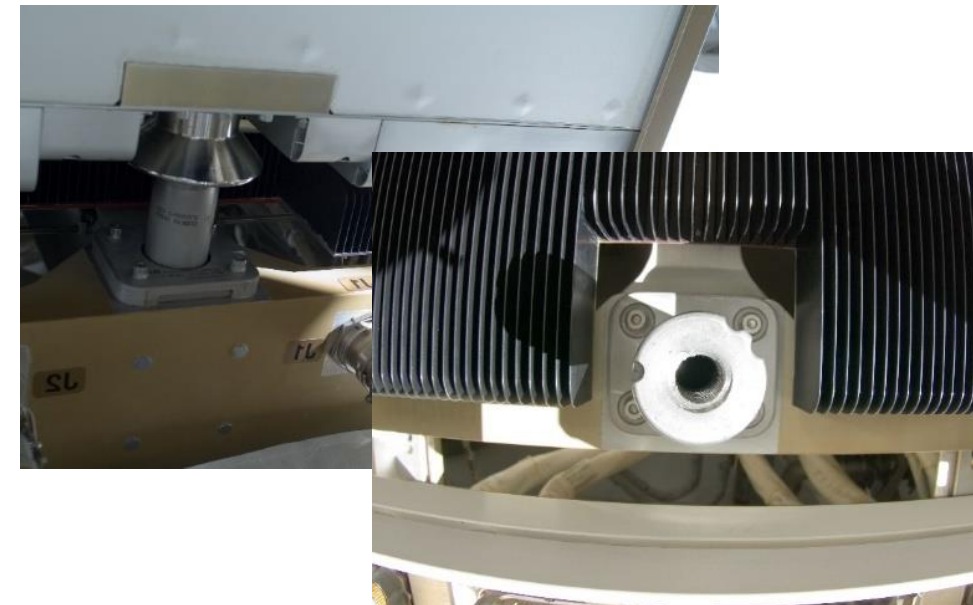
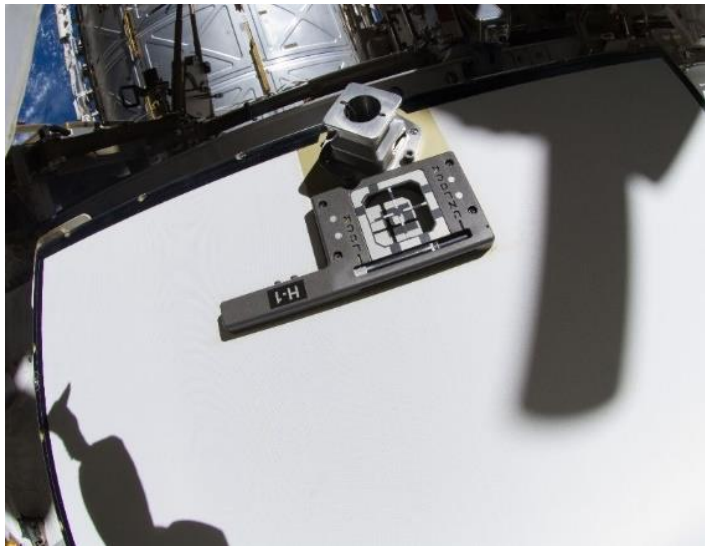
Two Bolts – How Hard Can It Be?



EVA Start



8 Hours Later



Six Days to Fix the Problem



- **Choreographed turnaround is now an unplanned shutdown**
 - Need to restore core ISS power channel as soon as possible
- **Found and utilized technicians that originally installed MBSU**
- **Sought input and expertise from hardware experts as well as crewmembers who had installed similar (H-Bolt) ORUs on ISS previously**
- **Determined there were two problems**
 - Foreign Object Debris had likely damaged the truss's bolt receptacle; possibly when originally installed but also during last spacewalk
 - Managing side loads on the jacking bolt was critically important
 - » Once the bolt receptacle was cleaned, dithering would be required!

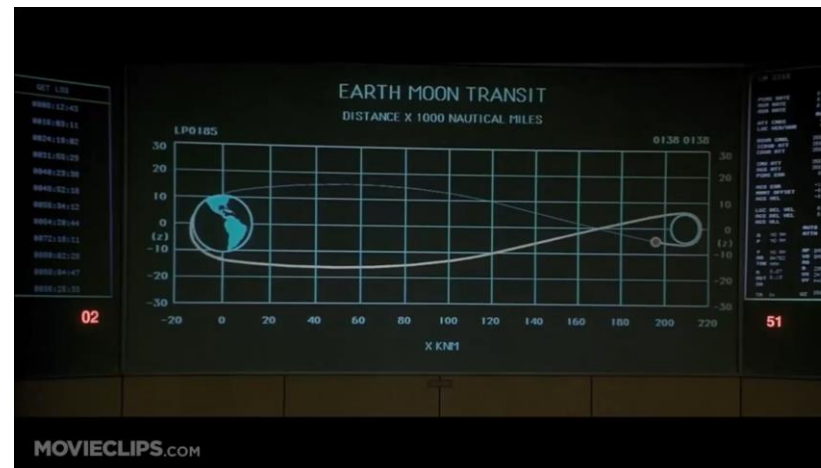




Thread Cleaning

No Hardware Store Trips Allowed

- How do you clean threads without a tap and die set?
 - In space
 - In a spacesuit
 - With only the tools and parts you have on hand
- Simple – challenge your teams to do it and get out of their way



MBSU Replacement Attempt #2



- **Step 1: Clean the threads**
 - **A: Take some 0 Gauge (large) wire, spread the individual conductors out, and create a 'wire brush.' Use Pistol Grip Tool (PGT, big cordless drill) to run wire brush in and out of receptacle**



Chimney Sweep



Ground version



On-orbit version



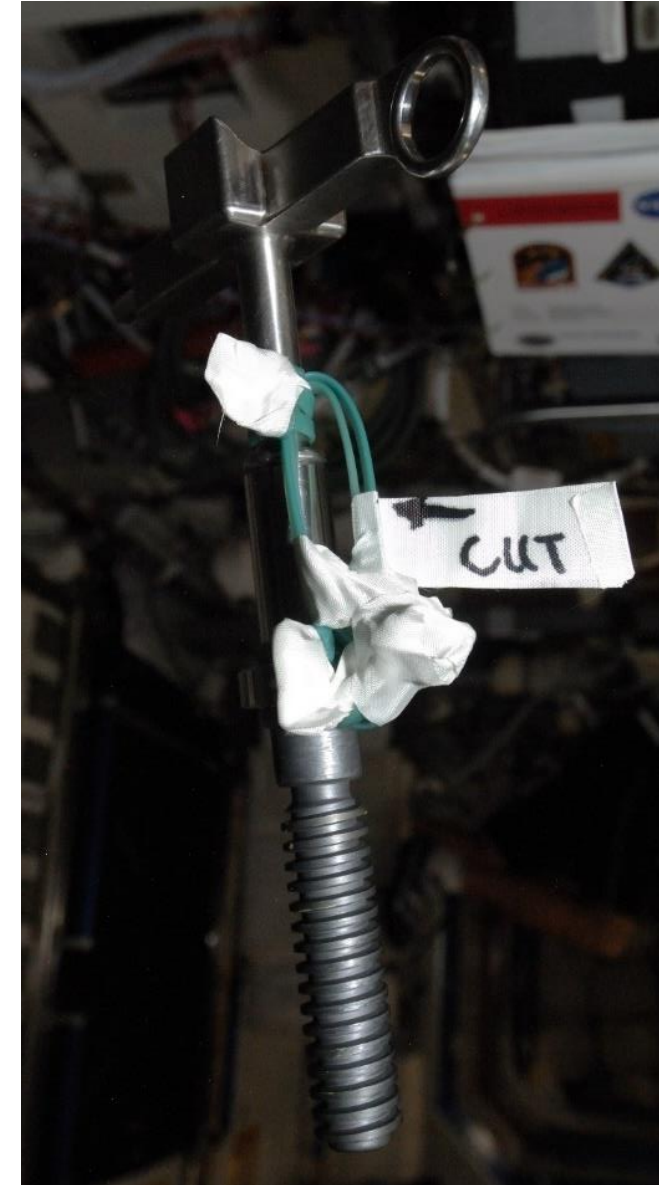
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 - B: **Disassemble spare computer in the ISS to retrieve its jacking bolt (same size bolt). Use it to chase the threads.**



ACME Bolt



MBSU Replacement Attempt #2



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- B: Disassemble spare computer in the ISS to retrieve its jacking bolt (same size bolt). Use it, attached to PGT, to chase the threads.
- **C: Use compressed air tool to blow debris out of threads**
- **D: Use modified toothbrush covered in grease for lubricating solar array joint, attached to PGT, to lubricate threads**
 - » Dry film lubricant was expected to have been removed on first spacewalk or by wire brush



Toothbrush



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- **Step 2: Install by dithering all the way**



Dithering



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 - D: Use modified toothbrush covered in grease for lubricating solar array joint, attached to PGT, to lubricate threads
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- **Step 2: Install by dithering all the way**
- **Step 3: Complete any tasks possible that were supposed to be performed on previous spacewalk**



Success!



- **Successful due to having pre-established a culture of high performance and independent leadership**
 - **Could not have turned this around in 6 days if stovepipes, micromanagement, and management oversight bottlenecks had prevailed**

Q: Why didn't we have an accident?

A: We leveraged off our heritage of being a High Performing, High Reliability Organization



High Performing Organizations



- **Leadership** – Leadership is aligned and effective deep within the organization
- **Design** – The structure is lean and reflects the organization's strategic focus
- **People** – The organization effectively translates business strategy into a powerful people strategy, attracting and retaining the most capable individuals
- **Change Management** – The organization can drive and sustain large-scale change and anticipate and adapt
- **Culture and Engagement** – The culture is shaped to achieve strategic goals. Employees pursue corporate objectives.



Source: Bhalla, Vikram; Caye, Jean-Michel; Dyer, Andrew; Dymond, Lisa; Morieux, Yves; Orlander, Paul (2011). "[High-Performance Organizations, The Secrets of Their Success](#)," Used with permission



High Reliability Organizations

- We were **mindful** that we had the right ...
- Circumstances
 - Sensitivity to Operations
- Processes
 - Reluctance to Simplify Interpretations
- Culture
 - Preoccupation with Failure
 - Commitment to Resilience
 - Deference to Expertise



Source: Weick, Karl E.; Kathleen M. Sutcliffe (2001). *Managing the Unexpected - Assuring High Performance in an Age of Complexity*. San Francisco, CA, USA: Jossey-Bass. pp. 10–17. ISBN 0-7879-5627-9



Success Enablers



- **Leadership development**
 - Infuse in culture of management, engineering, operations, crews
 - Purposeful development from the very beginning
 - Empower leadership at the lowest possible levels
- **Collaboration across organization**
 - Not just within operations organizations but across management, engineering, customers, operations, crew
 - Collaboration is a success multiplier – as long as the team at the end of the spear (operations) can translate it into execution
- **Paradigm shifts**
 - Look for them, be open to them, welcome them – even when it's painful
- **Designing for operability, reliability, and maintainability increases mission adaptability and flexibility**



Links and Information



- **Social Media**

- Twitter
 - » Ed: @Carbon_Flight
 - » NASA: @NASA
 - » Space Station: @Space_Station
 - » Astronauts: @NASA_Astronauts
- Snapchat
 - » Ed: cflight78
 - » NASA: NASA
- Facebook: carbonfd@gmail.com
- LinkedIn: <https://www.linkedin.com/in/edvancise>

- **Internet Links**

- Spot the Space Station from nearly anywhere on Earth:
<http://spotthestation.nasa.gov>
- More on the Space Station:
http://www.nasa.gov/mission_pages/station/main/index.html
- More on humans going beyond Earth:
<http://www.nasa.gov/topics/journeytomars/index.html>
- More on our solar system:
<http://www.nasa.gov/topics/solarsystem/index.html>

- **Video:**

- NASA Television:
www.nasa.gov/multimedia/nasatv/index.html
- NASA High Definition Earth Views from ISS:
<http://www.ustream.tv/channel/iss-hdev-payload>
- Live video (external or internal) from ISS:
<http://www.ustream.tv/channel/iss-hdev-payload>
- ISS Symphony: <https://youtu.be/wgdbZhnFD5g>
- Riding the Boosters: <https://youtu.be/2aCOyOvOw5c>
- Longer booster video: https://youtu.be/cLI7oqdm_B8

